# Techno-Economic Analysis of Hydrogen Production by Gasification of Biomass

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## Objectives

- To determine the economics of hydrogen production by gasification of three biomass candidates: bagasse, switchgrass, and nutshells
- To optimize hydrogen production for use in proton exchange membrane (PEM) fuel cells
- To identify the economic and technical barriers associated with biomass gasification

## Technical Barriers

This project addresses the following technical barriers from the Hydrogen Production section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- F. Feedstock Cost and Availability
- G. Efficiency of Gasification, Pyrolysis, and Reforming Technology
- AB.Hydrogen Separation and Purification

## Approach

- Determine the cost and availability of the three candidate biomass feedstocks.
- Design a process scheme for the production of hydrogen.
- Determine optimal hydrogen production through the testing of various simulation cases.
- Analyze research and simulation results to determine technical and economic feasibility.
- Determine the commercialization barriers to the production of hydrogen from biomass.

## Accomplishments

- Estimated the cost and availability of all three biomass feedstocks.
- Determined the current technologies available for biomass feeding and hot gas cleanup.
- Simulated and optimized the production of hydrogen through the use of an empirical, GTI proprietary gasifier model and a HYSYS® design and simulation package.
- Performed an economic analysis of the production of hydrogen from the three biomass feedstocks.
- Evaluated current public programs available to reduce the cost of biomass as a feedstock.
- Determined the technical, economic, and psychological barriers to the commercialization of hydrogen from biomass.

## Future Directions

The following areas are currently being pursued by GTI, however they are not funded under this project.

- Conduct experimental testing to verify the results obtained in this paper study.
- Evaluate an economical way to clean syngas at reforming temperatures.
- Determine suitable membrane materials that will promote reforming and separation.
- Further evaluate and test pressurized biomass feeding systems on various feedstocks.

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## Introduction

Biomass represents a large potential feedstock resource for environmentally clean processes that produce power or chemicals. It lends itself to both biological and thermal conversion processes, and both options are currently being explored. Hydrogen can be produced in a variety of ways. The majority of the hydrogen produced in this country is produced through natural gas reforming and is used as chemical feedstock in refinery operations.

In this study, the production of hydrogen by gasification of biomass is examined. Biomass is defined as organic matter that is available on a renewable basis through natural processes or as a by-product of processes that use renewable resources. The majority of biomass is used in combustion processes in mills that produce electricity for end-use product generation. This project explores the use of hydrogen as a fuel derived from gasification of three candidate biomass feedstocks: bagasse, switchgrass, and a nutshell mix consisting of 40% almond nutshell, 40% almond prunings, and 20% walnut shell.

## Approach

In this study, an assessment of the technical and economic potential of producing hydrogen from biomass gasification is made. The resource base is assessed to determine process scale potential from information on feedstock costs and availability. Solids handling systems are reviewed. A GTI proprietary gasifier model is used in combination with a HYSYS® design and simulation program to determine the amount of hydrogen that can be produced from each candidate biomass feed. Cost estimations are developed, and government programs and incentives are analyzed. Finally, the barriers to the production and commercialization of hydrogen from biomass are determined. The end-use of the hydrogen produced from this system is small PEM fuel cells for automobiles.

## Results

Analysis of the resource base determined bagasse and switchgrass should be analyzed on a scale of 500, 1000, and 2000 tonnes/day and mixed nutshells at 500 tonnes/day. Simulation results were obtained for 500 tonnes/day biomass fed to the gasifier at moisture contents of 20% for bagasse, 12% for switchgrass, and 12.5% for the nutshell mix. A scaling factor of 1 can be used to determine hydrogen production from an increased feed rate (i.e. doubling the feed rate will double the amount of hydrogen produced). Process flow diagrams were developed for all three cases and are very similar with the exception of the need for a dryer for the bagasse case, as shown in Figure 1 (the initial moisture content of the feed is 50% and must be reduced to 20% for feed into the gasifier) [1].

The flow streams and sizes from the process flow scheme were used to adjust the scale and unit

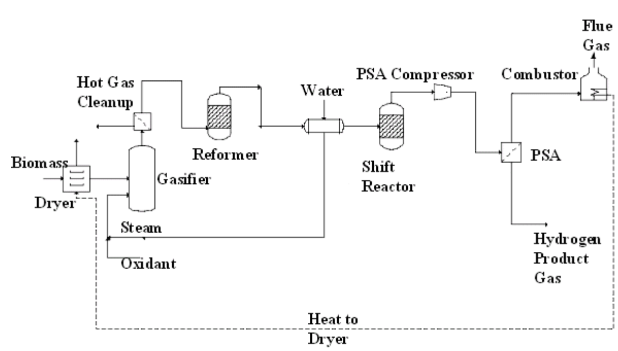


**Figure 1.** Process Flow Diagram of Bagasse Case with a Dryer (PSA = pressure swing adsorption)

operations that had previously been the subject of cost and design studies by EPRI and GTI. Previous work done for GTI had provided a very detailed breakdown of capital costs, including labor hours on many categories of construction and installation. The work done by EPRI developed cost breakdowns for biomass power systems using biomass feedstocks. Scaling of costs to adjust to the sizes desired for the cases studied here was accomplished according to the following general rule: power law scaling of 0.7 for the solids handling, gasification, gas cleaning, shifting, and purification systems, and 0.8 for the power, steam, balance of plant, general facilities, and overall combined cycle system scaling. Drying and steam turbine components were scaled at a 0.6 power law. Hydrogen production rates and the resulting economics are shown in Table 1 [1].

The economic results achieved in this study are comparable to those from steam methane reforming. For steam methane reforming plants that produce approximately 1.5 million $Nm^3$/day, the cost of hydrogen production ranges from $5.85/GJ ($3.00/GJ natural gas) [2] to $7.46/GJ ($4.50/GJ natural gas) [3]. This comparison is shown in Figure 2.

## Conclusions

Hydrogen is a valuable fuel that can provide sustainable energy for fuel cell vehicles. The majority of hydrogen is produced by steam methane reforming of natural gas, where average prices of $5.50 to $7.50 per gigajoule can be realized for larger facilities. At low natural gas prices, this is the least expensive way to produce hydrogen, but it relies on a non-renewable, fossil fuel.

Biomass gasification represents an alternative means to produce hydrogen. This study evaluated hydrogen production by gasification of three biomass feedstocks: bagasse, switchgrass, and a nutshell mix. The process scheme involved feeding, gasifying, cleaning, reforming, shifting, and purifying to produce a hydrogen stream with better than 99.9% purity. The economics of hydrogen production by gasification of biomass predict that hydrogen can be

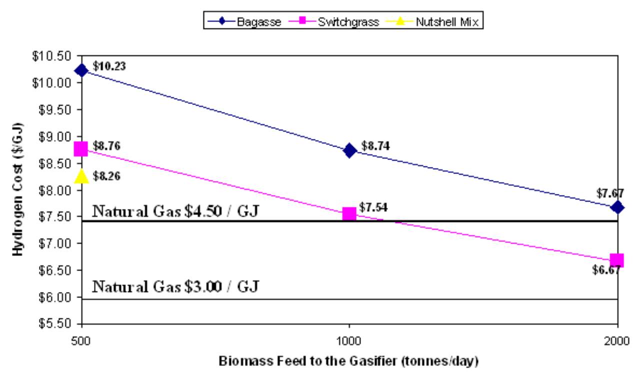


**Figure 2.** Estimated Cost Comparison of Hydrogen Production

**Table 1. Economic Results for Gasification of Three Biomass Feedstocks**

| | Gasifier Feed Rate | Hydrogen Produced | | Feedstock Cost | Capital Cost | $H_2$ Cost (15% IRR) |
|---|---|---|---|---|---|---|
| Feedstock | Dry Tonnes / Day | Tonnes / Day | $Nm^3$ / Day | US $ / GJ | US $ Million | US $ / GJ |
| Bagasse | 400 | 13.2 | 347,000 | 1.50 | 37.0 | 10.23 |
| | 800 | 62.5 | 695,000 | 1.50 | 61.1 | 8.74 |
| | 1600 | 125 | 1,390,000 | 1.50 | 100.9 | 7.67 |
| Switchgrass | 440 | 37.0 | 412,000 | 1.50 | 36.5 | 8.76 |
| | 880 | 74.0 | 824,000 | 1.50 | 60.6 | 7.54 |
| | 1760 | 148 | 1,648,000 | 1.50 | 100.9 | 6.67 |
| Nutshell Mix | 438 | 38.7 | 488,000 | 1.50 | 36.3 | 8.26 |

produced economically. Hydrogen prices from $6.50 - $10/GJ can be realized. As technology improves, natural gas prices increase, and government incentive programs evolve, biomass gasification will present an economical way to produce hydrogen for use in PEM fuel cells and other energy consuming systems.

## References


1. D. Bowen, F. Lau, R. Dihu, S. Doong, R. Remick, R. Slimane, R. Zabransky, E. Hughes, and S. Turn, "Techno-Economic Analysis of Hydrogen Production by Gasification of Biomass." Final Report to U.S. Dept. of Energy, Contract DE-FC36-01GO11089, June 2003.

2. P. Morris, "Clean Fuels Means Hydrogen, Where Will It Come From and What Will It Cost?" Air Products PLC, http://www.airproducts.com/auto-oil/techpaper-morris/htm.

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## FY 2003 Publications/Presentations

1. D. Bowen, F. Lau, R. Dihu, S. Doong, R. Remick, R. Slimane, R. Zabransky, E. Hughes, and S. Turn, "Techno-Economic Analysis of Hydrogen Production by Gasification of Biomass." Final Report to U.S. Dept. of Energy, Contract DE-FC36-01GO11089, June 2003.

2. D. Bowen, F. Lau. Poster presentation at the May 2003 US DOE Hydrogen and Fuel Cell Program Merit Review.

3. D. Bowen, F. Lau, R. Dihu, S. Doong, R. Remick, R. Slimane, R. Zabransky, E. Hughes, and S. Turn, "Hydrogen from Biomass Gasification." Canadian Hydrogen Association and Fuel Cells Canada Conference, Vancouver, BC, Canada, June 2003.

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